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RESEARCH PAPER

Inhibiting water evaporation of sandy soil by the soil particles modified with Japanese wax

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Abstract: This study was conducted to resolve the problems of water conservation of sandy soil in desertification areas. The surface of soil particles was modified by molecules of natural Japanese wax through some specially screened surfactant. The modified particles were then well sprayed onto the sand, which was placed in an artificial climate box with simulating desert environment, to form a soil film with effect of suppressing water and gas-permeability. Structure of soil film was analyzed by means of X-ray diffraction (XRD) and infrared spectrometry (IR). And its mechanism of water inhibition was illustrated with DSC and TG curves. Its influence on grass-planting was tested through the instruments of water detector. The results show that sorbitol anhydride stearate（Span 80）could well disperse the Japanese wax and make it combine with the clay which is also dispersed. The pores among soil particles grew smaller and turned from hydrophilic into hydrophobic, in which way resistance to water penetrating through the film was increased. Experimental grass grows normally on sandy soil with the soil film in the artificial desert climate box, indicating that the soil particles modified with Japanese wax is an effective method to inhibit water evaporation.

Keywords: Japanese wax; surfactant; desert soil; hydrophobic soil film

Introduction

Desertification has become a serious environmental problem in the world today, as it can cause soil fallow, abnormal weather, frequent sandstorms, and other natural disasters. With an annual increase of 2 460 km^2 in area of desertification, China's total area of desertification has been more than that of the arable lands, covering more than 470 counties (Wang 2000; Wei et al. 1997). In China, the annual evaporation rate of desert areas is as high as 1200–3500 mm, while the annual precipitation is only 20–350 mm (Zhu et al. 1999). Ecological restoration in those desertification areas becomes very difficult because of low survival rate of plant. Moisture condition is regarded as one of the key factors for ecological restoration in the desertification areas; however, frequent watering cannot guarantee the survival rate of weeds because plant has very limited utilization of the watering.

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Research on water conserving and sand binding can be traced back to the 19th century. However, no effective research was achieved until the 1950s (Wang et al., 2003). The high water-absorbing resin was first used for agriculture in the United States during the mid-1970s, and it was introduced into China in the 1980s. The water retention agent may absorb water from the plant in the absence of external water (such as rainwater), which hinders its use. The former Soviet Union used emulsified asphalt to control desertification in the 1970s and received obvious effectiveness; however, due to the fact that the plant cannot restore normally and the transportation costs too much, this method is restricted in the long-term use.

In the present study, wood-wax, which can be easily dispersed into small molecules, was modified onto the clay surface in the form of molecules through special surfactant. Then the modified composite mud was sprayed onto sand surface, forming a thin layer of soil, through which gas can penetrate easily while water not. The evaporation of moisture was kept under the film and the conservation of soil moisture was realized, which is conducive to plant growth. In this research, soil particles, which can be obtained from the desert areas, was modified with a small quantity of environment-friendly Japanese wax and surfactant. This method can overcome the shortcomings of traditional methods in transports and high costs, making this research more operational and environment-protective.

Materials and methods

Sand from the Ulan Buh desert, together with a certain amount of distilled water, was fully stirred. Soil suspension was prepared

by removing the sediment layer from the mixture after standing for one minute, then filtered and dried to get soil particles. The Japanese wax which is well hydrophobic was chosen as a hydrophobic modification material. Several nonionic surfactants, Span80 (S), octylphenol ethoxylates (OP-4) (P), emulsifier EL-10 (EL-10) (E1), emulsifier EL-20 (EL-20) (E2), emulsifier EL-10 (EL-80) (E8), polyoxyethylene nonylphenol ether (Tx-10) (B), and an ionic surfactant—sodium dodecyl benzene sulfonate (L), were used to make the Japanese wax and soil particles well integrated.

Japanese wax of 0.5 g was mixed with one kind of surfactants, each with the amount of 3, 6, 9, 12, 14 g separately. The mixture was sheared for 5 min by a high-speed emulsion shearing machine to form emulsion. The emulsion was placed on a magnetic blender in certain volume and stirred powerfully for 2 min, then, added with 3-g soil particles and stirred until the serosity was evenly distributed. Finally, the serosity was well leached onto the sand with a relative humidity of 40%. A layer of composite soil membrane was formed on the surface of sand in uniform. For planting grass, seeds of grass must be evenly sprinkled on sand surface in advance, with the follow-up steps.

The transmittance of the emulsion was detected through an Ultraviolet Spectrometer to determine its dispersion. The samples were put into an artificial climate box with temperature of 50ºC, humidity of 0% (no extra humidity provided by the artificial climate box) and light intensity (equivalent to 30000 Lx). The test continued for eight days under these conditions. Weight losses of the sand with the soil films were measured every 24 h with the JY1001 sophisticated electronic scale from the third day. Scanning Electron Microscopy (SEM) was used to analyze the micro-structure of the composite soil membrane, as well as the combination between hydrophobic modifying components and the soil particles. The interlamellar spacing and the constituents of the composite films were tested by means of X-ray diffraction (XRD). Using infrared spectrometry (IR), the structure and composition were analyzed. The characteristics of water desorption of the emulsion and soil films were illustrated with DSC and TG curves.

Results and discussion

The moisture content curves of sandy soil with 6-g surfactant are shown in Fig. 1. Sandy soil with surfactants P, E1, E2, E8, L and B lost a great amount of water after three days, as the surfaces of these samples cracked in variety, while the soil film of surfactant S did not lose much. In addition, curve of S slopes gently and the moisture is suitable for plants growth. Therefore, we confirm that surfactant S contributes to forming an integral film and keeping soil from packing, and it was used for the follow-up tests.

The molecular structure of surfactant S is shown in Fig. 2. Its lipophilic groups—the hydrocarbon chain and the Japanese wax molecules attract to each other as intermolecular forces exist. While the hydrogen-polar combine with polar water molecules to form hydrogen bonds. Thus, the Japanese wax was scattered into micro-molecule and the emulsion formed. As is shown in Fig. 3, the transmission rate of emulsion is zero in the wavelength of 300 nm and above. It is indicated that Japanese wax is dispersed by surfactant S to form the emulsion that is well dispersed.

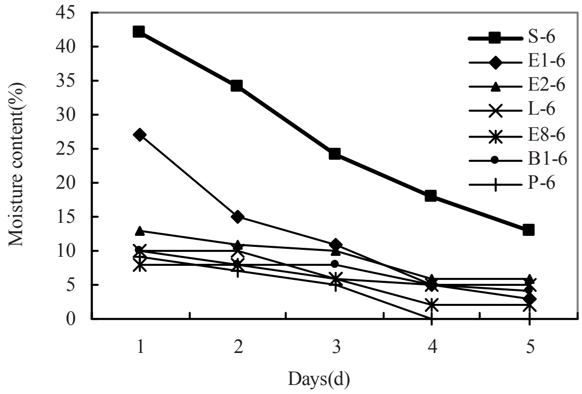

Fig. 1 Moisture curve with surfactant amount of 6 g

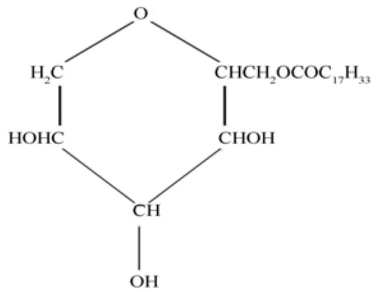

Fig. 2 Molecular structure of surfactant Span80

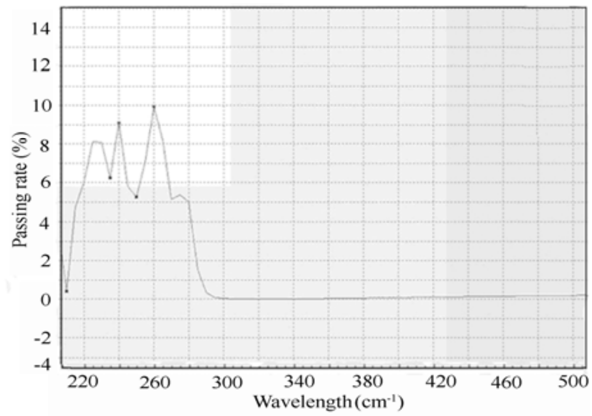

Fig. 3 Transmittance of emulsion Span80

There are variant crystal lattice metalepsises in soil in nature. When soil particles dissolve in water, there are extra cations existing among interlaminations and their existing makes the particles negative. According to Gibbs principle of free energy minimum, if soil particles are added into the emulsion, the surfactant hydrogen- polar has precedence over symmetric water molecule to combine with the negative group in form of hydrogen bond. Thus, the soil particles were modified with the wax molecules on their surfaces. The micro-structures of the original soil and the modified samples were analyzed with Scanning Electron Microscopy (SEM). The micrographs in Fig. 4 indicate that there are obviously luminescent substances on the surface of

modified soil particles. It was found that particles were coated by the modifying agent and scattered into much smaller particles, and the intergranular space grew smaller, too.

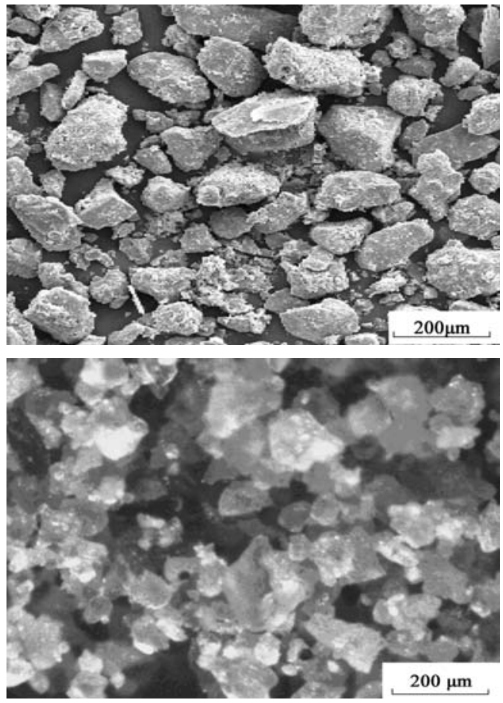

Fig. 4 Micrographs of original sample and modified sample
(a) Original sample (b) Modified sample

In Fig. 5, there is nearly no difference between the interlamellar spacing of modified soil and original sample. It is indicated that the modification of soil particles by Japanese wax and surfactant S does not change the interlamellar spacing of soil layers, and that ion exchange does not include ions among soil layers.

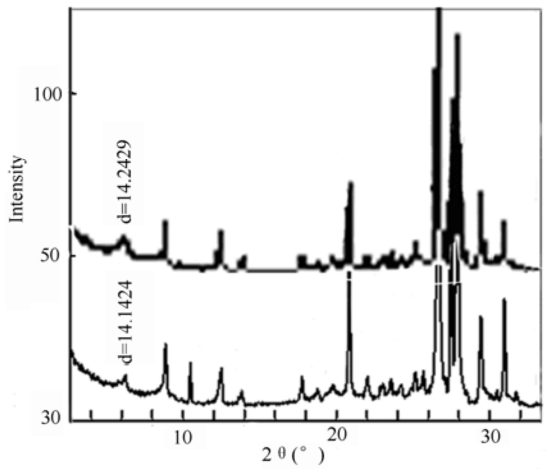

Fig. 5 X-ray of original and modified sample

Comparing of the two characteristics peaks in the infrared spectrograms in Fig. 6, we can see that the peaks of soil has not changed before and after modified, with the exception of a few new waves at 3000 cm^{-1}. It means that the modification of original soil samples did not change the composition of the particles.

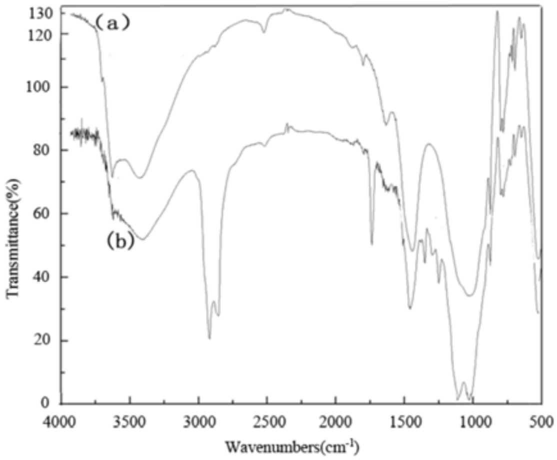

Fig. 6 Infra-red spectrogram of two samples

TG and DSC curves of emulsions S at different concentrations showed that degrees of emulsion with different surfactant concentrations were illustrated (Fig. 7). When using surfactant S of 0.6g (S-6), the polarity end has almost no control on water molecule, and the hydrophobic end has promoted water evaporation with water loss of 45% at 50ºC. Improving the emulsion extent by increasing the surfactant content can inhibit water evaporation. The evaporation of S9 (dosage of surfactant S, 0.9 g) began at nearly 100ºC. It demonstrates that the best dosage of S must be more than 9 g. The TG and DSC curves of modified soil films are shown in Fig. 8.

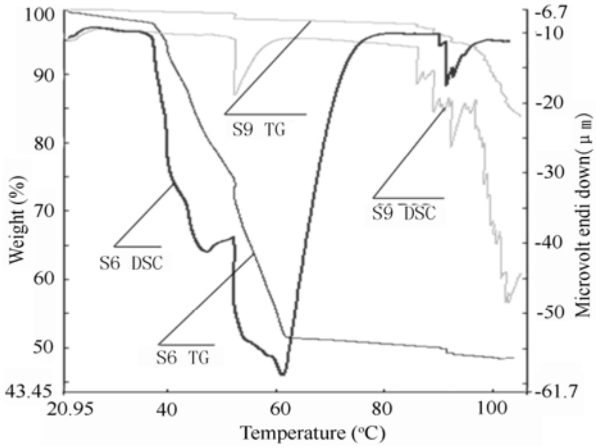

Fig. 7 Thermal analysis correlation between Span80-6(S6) and Span80-9(S9)

There was almost no weight change before the temperature of sample reached 600ºC. It can be concluded that the surface of soil particles is fully and evenly coated with Japanese wax, and the free water among clay layers does not dissipate until the Japanese wax lost its effectiveness.

To evaluate the influence of surfactant in different concentrations on the germination rate of weeds, grass-planting test was carried out in the artificial climate box simulating climate of the desert in laboratory. The result was shown in Fig. 9. It is found

that the soil film with less surfactant lost water in itself too much quickly to keep the excessive water in sand soil, even if the corresponding emulsion is highly hydrophobicity will do no good to the growth of weeds. However, the soil particles will be coated too thickly if using too much surfactant. Thus the intergranular space was plugged and the permeation of gas was hindered, making the germination rate dropped dramatically. Surfactant S in moderate amount of 12 g, can scatter the Japanese wax properly onto surface of soil particles. The film formed in that concentration can keep water well and the gas can permeate through the gaps as usual.

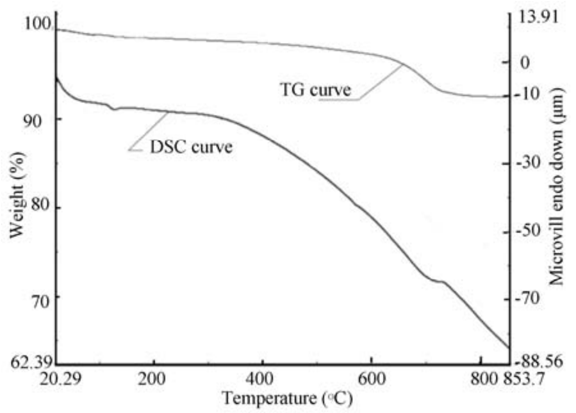

Fig. 8 Thermal analysis of modified soil sample

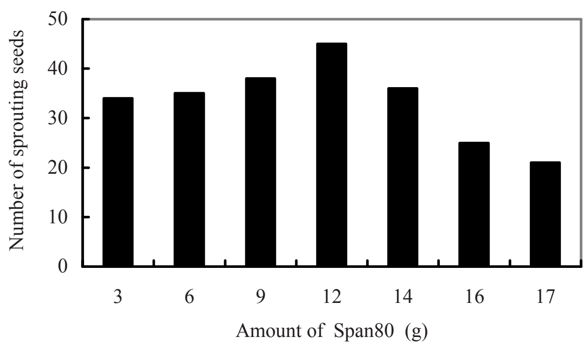

Fig. 9 Effect of grass-planting on Span80

To sum up, surfactant S can isolate and scatter both the Japanese wax and the soil particles. The particles grew smaller. The Japanese wax was emulsified and coated completely in the surface of soil particles to form a film without cracking. Soil particles in the film were coated with hydrophobic groups from the hydrophobic modifying agent, which turned the particles from hydrophilic into hydrophobic. Meanwhile, surfactant S dispersed soil particles into smaller ones. And the hydrophobic pores grew much smaller so that water could not soak on the particles surface. Diameter of the globules touching on the hydrophobic surface increased under the tensile force of water to inhibit its evaporation. The whole modification mechanism was illustrated in Fig. 10. Thus, areas with high evaporation rate are hopeful to realize the surface water conservation and vegetation restoration. And now we are doing much more research to improve the hydrophobic film to regulate its structure and membrane stress spontaneously with different illuminant and temperature. It will be more conducive to water conservation in sand soil.

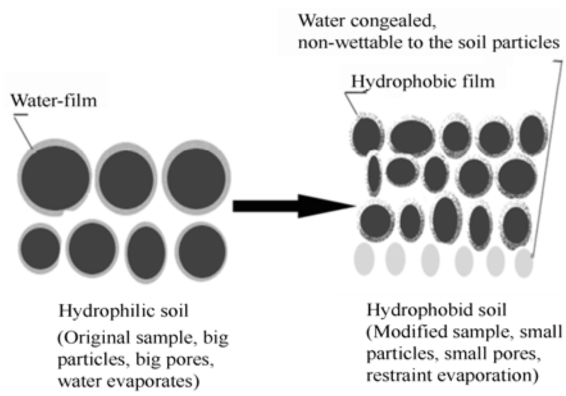

Fig. 10 Sketch of modification mechanism

Conclusions

Compared to the other surfactants used in this test, the modified clay prepared with surfactant S, turned into hydrophobicity with high water-retention capacity. The amount of emulsion should be controlled below 12 mL for the growth of weeds.

The retention mechanism of the soil film was analyzed. The results indicate that the modified clay is dispersed into small particles by surfactant S with the pores among the particles growing smaller. And the surface of soil particles is modified with the Japanese wax. And it turned those pores from hydrophilicity into hydrophobicity. The resistance to water going through the film is increased and the penetrating water is kept below the film.

Both the emulsion and the film can be easily prepared in desert area on a large scale. The clay, main material used in this paper, can be got from the desert. That means that the research can provide the method to control desertification in the desert region by low cost and no pollution materials.

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